# A study on Mechanical characterization of Crump Rubber filled GlassMicroballoons Reinforced High density Polyethylene Composite

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## Abstract
Syntactic foams are particulate polymer matrix composites made of microspheres spread throughout a matrix. Airplanes, spacecraft, and ships are all constructed using synthetic foams. These are lighter crystalline polymers employed for packaging, thermal insulation, sound absorption, building of undersea vehicles, and as the core of aircraft, sandwich structures. In this study, a Crump rubber-filled HDPE GMB and Syntactic foam polymer matrix composites is synthesized by mechanical mixing using Pelletizer and through injection moulding. Composites were fabricated accordingly keeping GMB composition constant of 20% and by varying percentage of Crump Rubber (5%, 10% and 15%), to study the impact of altering the volume percentage of Crump Rubber. Optimizing blending parameters based on experimental density estimates and filler fragmentation. Mechanical Characterization of the composite is evaluated according to ASTM standards. Study acknowledges the progressive improvement in mechanical characteristics (Impact, Tensile, Flexural and Hardness strengths) as Crump rubber is added to the composite.3

## Introduction
Innovative cutting edge technology has quickly modernized the usage of intelligent material components and structures in engineering applications. Technological innovation entails upgrading and developing new concepts so as to preserve weight and size, performance, affordability, and longevity. Intelligent materials, such as composites, are advantageous due

to their adaptable qualities and ability to be manipulated for a variety of engineering purposes. Composite materials are a mixture of two or more dissimilar materials and can be classified in various ways based on their size, matrix type, and other factors. Composite materials have become popular in engineering due to their strength-to-weight ratio, thermal and corrosion-resistant qualities. Polymer Matrix Composites (PMC's) are a common type of composite material, which consist of a fiber embedded in a thermoplastic or thermosetting matrix. PMC's have a wide range of applications, from small stop sign posts to large bridge decks and shoreline constructions.

Synthetic fibers, which were invented in the late 19th century, have desirable mechanical qualities and are used in applications with high loads. Syntactic foams are a class of synthetic materials with tailorable qualities that are lightweight, low density, and suitable for use in a wide range of engineering applications. They are often used for their thermal, mechanical, dielectric, electromagnetic, sound absorption, vibration, and insulating properties.

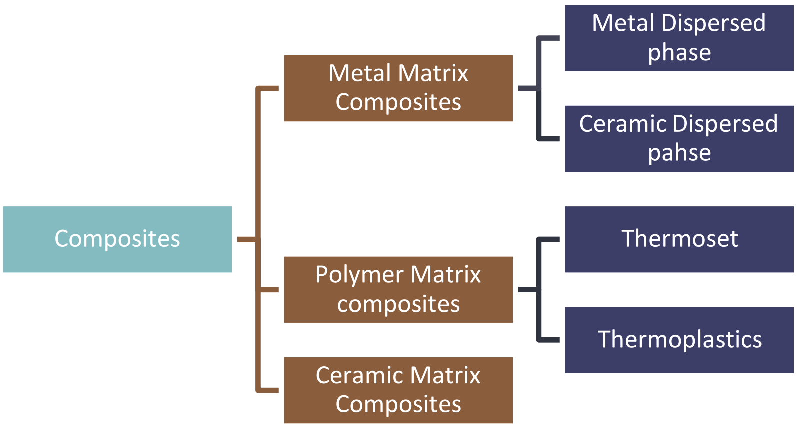


**Figure 1. Classification of composite materials**

The choice of matrix material, such as epoxy, vinyl ester, and polyester, is crucial in shaping the final attributes of a composite material. Fillers, including crystalline silica and glass Microballoons, are often used to increase strength and reduce costs in composites. They also manage dimensions and lower composite shrinkage.

In the current work, an attempt is made to fabricate a Polymer composite material by Injection moulding process, with notable mechanical characteristics for engineering applications. A comparative study is conducted by characterizing specimens with increasing filler composition, to study effect of filler on various properties.

## 2. Literature Review

Literature review is the basis of every research project. Experiment technique, characterization, and assessment are described in the literature. Literature-derived information is recognized and used in the current study. This research focuses on the production of natural and synthetic FRPs and the investigation of their mechanical and tribological characteristics.

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Afolabi et al. [1] studied ways to reduce porosity in syntactic foam by examining various mechanical, microstructural, and curing conditions. They found that vacuum-aided mold filling resulted in a higher relative density, compressive modulus, and compressive strength compared to conventional mold casting.

Katona et al. [2] investigated the cyclic loading of metal matrix syntactic foams made of different grades of aluminum alloys and oxide ceramic spheres. They found that the softer matrix phase had greater fatigue stress values than the stiffer matrix material, and larger hollow ceramic spheres outperformed smaller, more brittle ones.

Gupta and colleagues [3] synthesized and characterized microballoon vinyl ester/glass syntactic foams, and found that several formulations had compressive strength and moduli comparable to matrix resin.

Kim et al. [4] studied compression-induced failure in buoyant syntactic foams made of glass hollow microspheres and epoxy resin. They observed two failure categories with different mechanisms: layered crushing and longitudinal splitting.

Sankaran et al [5] explained the multi functionality and usefulness of syntactic foams, including their strength in compression, flexure, short-beam, tension, and impact. Conductive fibers/fillers can be added to create microwave-transparent foams and sandwich composites for EMI shielding and other purposes.

Orabulov et al. [6] tested eight metal matrix syntactic foams (MMSFs) for compressibility and found that engineering factors such as matrix material chemical composition, microballoon size, heat treatment, and compression test temperature affected compressive properties.

Dando et al. [7] evaluated the mechanical characteristics of carbon nanofibers and halloysite nanotubes in syntactic foam composed of thermoplastic microballoons. They found that nanofibers increased compressive strength and modulus, while nanotubes increased tensile strength.

Shunmugaswamy et al. [8] examined the influence of wall thickness and volume percentage of hollow particles on the dielectric constant of vinyl ester matrix/glass hollow particle syntactic foams. They found that a variety of syntactic foam compositions can be adjusted to have the same dielectric constants, allowing density and other characteristics to be separately tuned for different applications.

John et al. [9] compared nanoclay-reinforced cyanate ester syntactic foams to those without nanoclay and found that the nanoclay enhanced tensile, flexural, and compressive strengths and moduli, but decreased Tg.

Hong et al. [10] developed a microwave expansion technique for producing thermoset-matrix syntactic foam using expandable polystyrene (EPS) microspheres and epoxy resin. The specific flexural strength and modulus of the foam were comparable to pure epoxy.

Li et al. [11] studied the impact response and residual strength of a crump rubber modified syntactic foam containing up to 20% by volume of crump rubbers. They found that the rubberized syntactic foam was more effective in dissipating impact energy and retaining bending strength.

Pham et al. [12] investigated how adding crump rubber to syntactic foam can increase fracture toughness and energy absorption capacity. They found that the foam's fracture toughness and energy absorption capacity increased under static and impact stresses.
Lapkovskis et al. [13] explored methods for processing end-of-life tires to yield rubber crump, which can be used in the development of new industrial rubber products and composites. They used chemical, mechanochemical, and mechanical methods to generate crump rubber with varying percentages and chemical reactivity.

The fabrication of high-quality syntactic foam components in a variety of geometries and forms can satisfy the market's growing demand. Injection moulding is one approach for producing components made of syntactic foam with lower tooling costs and greater strength. The current study examines the use of Injection moulding at an industrial scale to produce Crump Rubber-Glass microballoons/HDPE syntactic foam composites.

From the above literature review, it is evident that there are limited research publications on the development of GMB/HDPE syntactic foam composites employing injection moulding. The current study suggests the fabrication of a low-cost glass microballoons reinforced Crump rubber filled high-density polyethylene (HDPE) composite. The literature survey on syntactic foams led a comprehensive and systematic investigation of these composites via experimental evaluation of their mechanical as well as physical characteristics.

## 3. Material and Methods

### 3.1. Materials

Primary components of Polymer composite consist of reinforcement, material, and additives. Each component of the composite imparts its qualities to the finished laminate; thus, it is necessary to find a blend of reinforcement and matrix phase with optimal attributes.

Crump Rubber HDPE Glass microballoons

**Figure 2. Materials Used**

#### 3.1.1 Crump Rubber (CR)

Crump is comprised of recycled, destructively chipped or hammered, used automobile tyres.

This material is produced by granulating, chipping, ageing with other specialists, freezing, then destroying, chipping, etc. Owing to these cycles and subsequent treatments, the crump elastic retains different quantities of the non-elastic substances/components utilized in the tire's original manufacture.

**Table 1. Properties of Crump Rubber [14]**

| Properties | Specification |
|---|---|
| **Specific Gravity** | 1.72 |
| **Density** | 1.15±0.05 g/cm3 |
| **Moisture Content** | 2% |
| **Fineness modulus** | 4.48% |
| **Young's Modulus (E)** | 2600 – 2900 MPa |
| **Tensile Strength** | 40 – 70 MPa |
| **Elongation at Break** | 25 – 50% |
| **Melting Point** | 200 C$^{o}$ |

Crump rubber (CR) is the recycled rubber generated by mechanically shearing or grinding tyres into tiny, gritty pieces of size between 75 µm - 4.75 mm. A variety of rubber compositions are used to construct tires. The total rubber hydrocarbon content has the greatest influence on the physical qualities of asphalt rubber (AR), followed by the natural rubber content. Crump rubber has considerable physical properties, It is seen that crump rubber improves resistance to deformations, water permeability, low-temperature cracks. Because of low water permeability CR are one of the components used in making roads. Since CR is elastic in nature CR material is used for vibration absorption. In this Work, CR with varying percentage of 5%, 10%, 15% is used as filler to study the characteristic consequences.

### 3.1.2 HDPE – Matrix

High-density polyethylene (HDPE) is an ethylene-based thermoplastic polymer. It is usually referred to as "alkathene" or "polythene". HDPE is used in the manufacturing of plastic bottles, Rust-resistant pipelines, membranes, and plastic planks due to its high strength-to-density ratio.

HDPE is renowned for its excellent ratio of strength to density. The HDPE density varies between 930 and 940 kg/m$^3$. HDPE has better intermolecular forces and tensile strength (38 MPa against 21 MPa) than LDPE, despite the fact that its density is only moderately higher than that of low-density polyethylene. The strength difference outweighs the density difference, providing HDPE a greater specific strength. It is also tougher, more opaque, and can endure temperatures of 120 °C/248 °F for brief durations. In contrast to polypropylene, high-density polyethylene cannot resist autoclaving conditions [15].

**Table 2. Properties of HDPE**

| Property | Specification |
|---|---|
| **Density (Kg/m3)** | 950 |
| **Water Absorption(24hr)** | <0.01% |
| **Thermal Expansion factor ($10^6$ $K^{-1}$)** | 100-200 |
| **Poisson's Ratio** | 0.46 |
| **Friction factor** | 0.29 |
| **Rockwell Hardness** | D 60-73 |
| **Elastic Modulus (GPa)** | 0.5-1.2 |
| **Impact Resistance, IZOD(J/m)** | 20-210 |
| **Yield Stress (MPa)** | 15-40 |

### 3.1.3 Glass microballoons (GMB) – Filler

GMBs are smooth-surfaced particles with a high crushing strength. GMBs are characterised by their spherical shape, low density, regulated size, excellent thermal conductivity, high compression strength, dielectric property, little moisture absorption, and exceptional acoustic insulation capability. Because of their low cost and extensive availability, these microspheres are used as filler in the production of composites from a variety of thermosetting polymers.

Polymer composites containing glass microballoons offer desired mechanical, thermal, and electrical properties, as well as increased dimensional stability at a lower cost. The required properties of thermoset foams reinforced with glass microballoons are the subject of substantial research [16].

Glass microballoon polymer-based thermosetting syntactic foam has multifunctional properties, such as low density, high specific compressive strength, thermal conductivity, and low moisture absorption, making it appropriate for structural applications in aerospace, automobile body parts, marine, etc. Nowadays, glass microballoon/ polymer composites provide immense opportunities in basic science and technology and create formidable challenges for future work in the field of polymer composites. In this Project, GMB of 20% composition is used as Reinforcement in all the sets of composites.

### 3.2 Fabrication Process

In this study, Crump rubber, HDPE, and GMB are combined in specific weight ratios for uniform distribution using injection molding. This method involves injecting molten plastic into a mold and then cooling it, making it suitable for large-scale production of intricate objects. The process begins with extrusion, where granules of the three materials are fed into a spinning screw through a feed mouth, and plastic compression occurs as it moves down the heated barrel. The heated barrel is regulated by independent PID controllers, generating zones of steadily rising temperature. The plastic is mixed and forced out as strands and transferred to a water bath pelletizing device to lower the temperature and ensure stability. Cooling is achieved by passing the plastic through cooling rollers, and the strands are then cut into small pellets using a spinning blade in the pelletizer's cutting chamber. These pellets are then fed into the injection molding machine for further use.

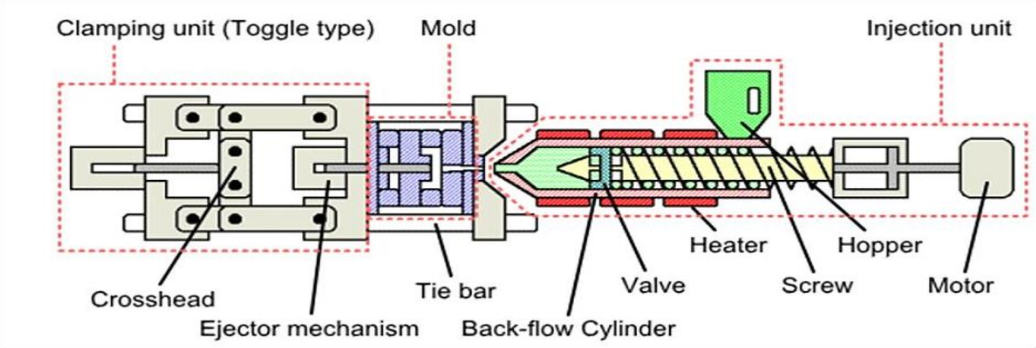


**Figure 3. Injection Moulding**

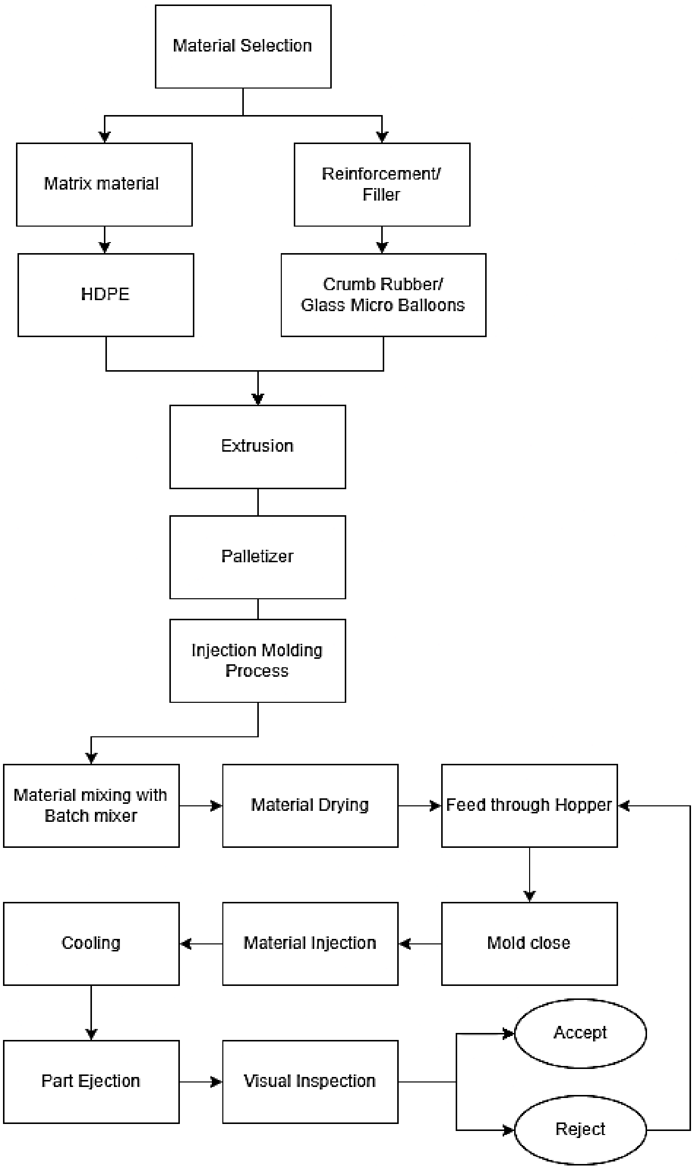

**Figure 5. Extrusion Machine**

**Figure 6. Pelletizer**

**Figure 7. Molds for Mechanical Testing Specimens**

The Injection Moulding machine receives GMB-HDPE-CR in the form of granules or pellets. The thermoforming machine melts the plastic into a liquid state. The injection moulding machine's nozzle subsequently injects molten plastic into the mould (injection pressure). The plastic liquid is now poured into the cavity of the mould. This will eventually solidify as it cools. Ejectors then propel the cooled, finished product out of the machine. The Derived specimens were further grinded to make it a finished product and sent further for testing process [17].

### 3.3 Mechanical Characterization

In the current research, the mechanical characteristics of Crump rubber, HDPE and Glass composites filled with varying percentages of Microballoons. Specimens were evaluated in accordance with various ASTM standards.

#### 3.3.1 Physical Characteristics

Figure 8. illustrates several ASTM standards for evaluating tensile, flexural, impact, and hardness properties. The Shore-Durometer (Shore-D) was used to assess the hardness of the

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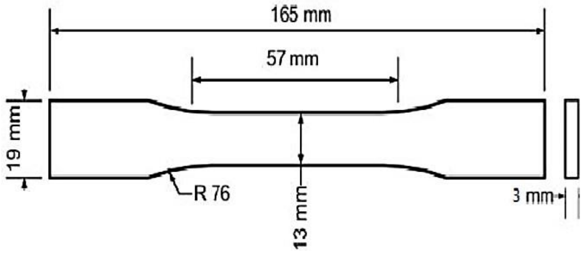
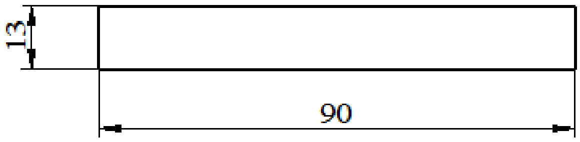
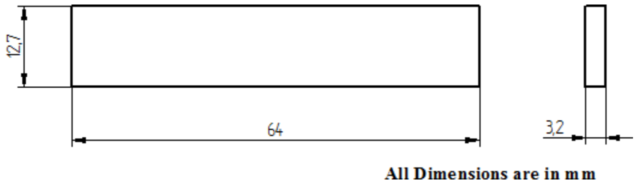
composites created to examine the influence of reinforcing and hybridization [18].

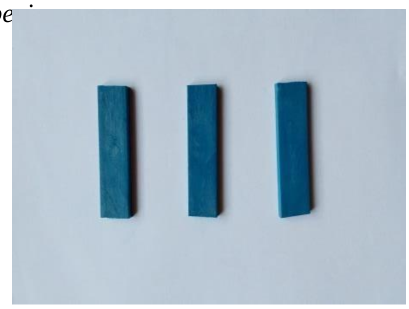



*ASTM D 638-03 Tensile test Specimens*




*ASTM D790-03 Flexural test Spe*



*ASTM D 256 Impact test Specimens/ ASTM D2240 Hardness test specimens*

**Figure 8. ASTM Standard Test Specimens**

## 4. Result and Discussion

### 4.1 Tensile Strength

The tensile strength of HDPE-Glass Microballoons composites with 5, 10, and 15% CR filler was determined by conducting a series of tensile tests in accordance with ASTM 790 standards using computerized universal testing equipment. Each set was put through three trials. From the test conducted, graphs of stress/strain were created. Stress/strain graphs for each specimen were retrieved remotely from the UTM using information sampling software.

Figure 11. depicts the stress-strain curve for composites comprising 15% Crump Rubber. It is obvious that the tensile strength of 15% Crump Rubber filler is greater. Figure 9, 10 depicts the stress-strain behaviour of 5% and 10% Crump Rubber filled composites. It is observed that stress increases linearly with load, up to the breaking point. In addition, 15% filled CR HDPE-Glass Microballoons composites have Ultimate Tensile strength of 15.99 MPa with 15 % elongation. Compared to 5%, 10% CR, UTS of 15% Crump Rubber composite seen to be

50 % higher than 5 % CR filled composite. Hence it can be concluded that addition of CR as filler to the composite improves Tensile strength. The results obtained from all the trials are very similar and nearer, showing efficient fabrication procedure. From the stress-strain curve it is noticed that curve seems to be linear, showing proper distribution of Crump Rubber particles along the composite. From Figure 12. It can be understood that, addition of CR Particles made composite much brittle as well adding capability to resist the load.

Table 3. Tensile Test Statistics for 5, 10, and 15% Crump Rubber filler Composite

| Composites | Sample No. | Peak Load (KN) | Avg. Peak Load (N) | % Elongation | UTS (MPa) | Avg. UTS (MPa) | Tensile Modulus (MPa) | Avg. Tensile Modulus (MPa) |
|---|---|---|---|---|---|---|---|---|
| 5 % CR | 1 | 379.99 | 309.54 | 4.076 | 12.29 | 10.15 | 356.917 | 332.795 |
| | 2 | 255.69 | | 2.580 | 8.76 | | 305.820 | |
| | 3 | 292.95 | | 3.018 | 9.413 | | 335.649 | |
| 10% CR | 1 | 443.74 | 428.05 | 3.47 | 12.17 | 12.11 | 296.92 | 375.09 |
| | 2 | 442.03 | | 2.99 | 12.56 | | 440.22 | |
| | 3 | 398.39 | | 3.31 | 11.62 | | 388.13 | |
| 15 % CR | 1 | 394.00 | 461.79 | 4.45 | 13.90 | 15.99 | 269.01 | 318.71 |
| | 2 | 496.18 | | 7.01 | 17.02 | | 243.17 | |
| | 3 | 495.19 | | 6.18 | 17.05 | | 443.94 | |

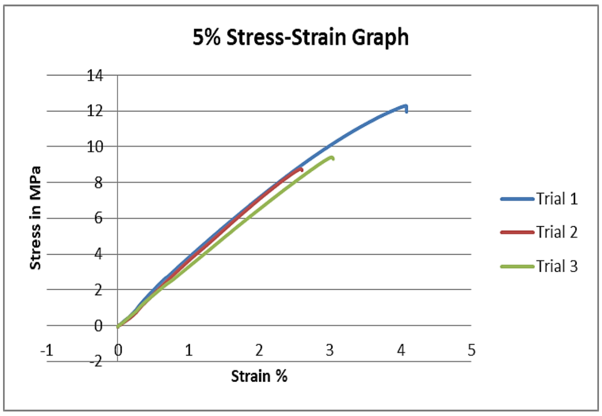



Figure 9. 5 % CR HDPE-GMB composite

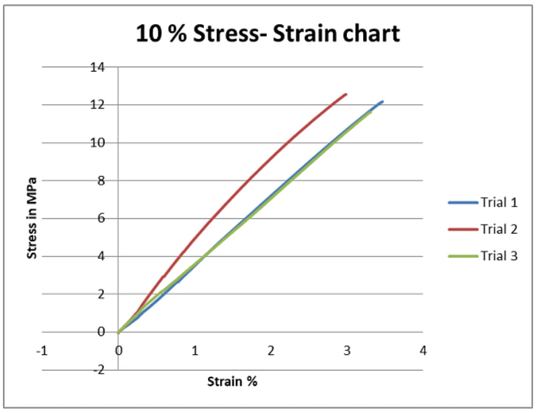



Figure 10. 10 % CR HDPE-GMB composite

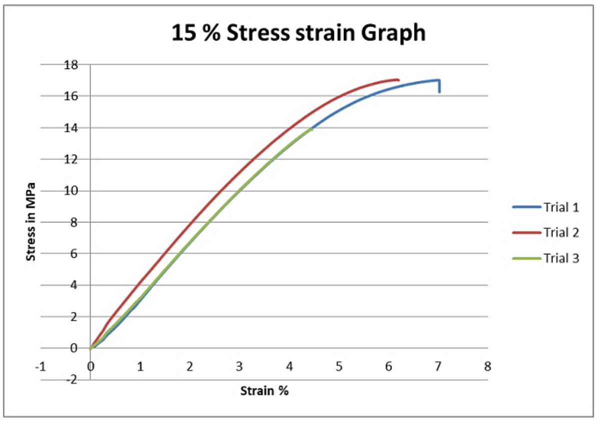



Figure 11. 15 % CR HDPE-GMB composite

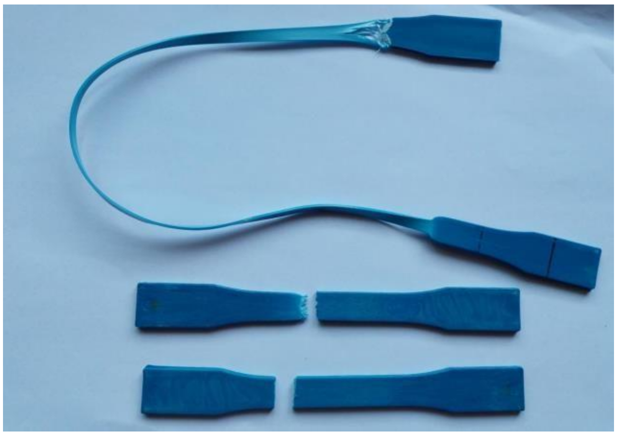


Figure 12. 5%, 10%, 15% CR Composite After Tensile Test

### 4.2 Flexural Strength

Using a UTM machine, the flexural strength of composites with various CR filler percentages was investigated in a set of three trials. The testing results are presented in Table 4 and Figures 13 and 14.

Table 4. Flexural strength 5, 10, and 15% CR filled composites

| Trials | 5% | 10% | 15% |
|---|---|---|---|
| 1 | 13.266 | 13.7698 | 22.41005 |
| 2 | 13.231 | 13.9404 | 23.33714 |
| 3 | 10.750 | 13.8797 | 24.81726 |
| Average (MPa) | 12.41544 | 13.8633 | 23.52148 |

The outcomes showed the average flexural strength of composite laminates. Since CR filler has higher adherence to reinforcements, the analysis reveal that composites containing higher Crump Rubber percentage have better flexural strength than other remaining composite laminates.

The flexural strength of the 5% Crump Rubber composite material was 12.4 MPa, as adding CR filler to the matrix shown an appreciable improvement. Owing of the beneficial bonding of CR particles to the with GMB, which overcomes the weak adherence between GMB HDPE and CR, the addition of fillers to HDPE-GMB also boosts flexural strength by nearly 100 % compared to 5 % CR Composite.

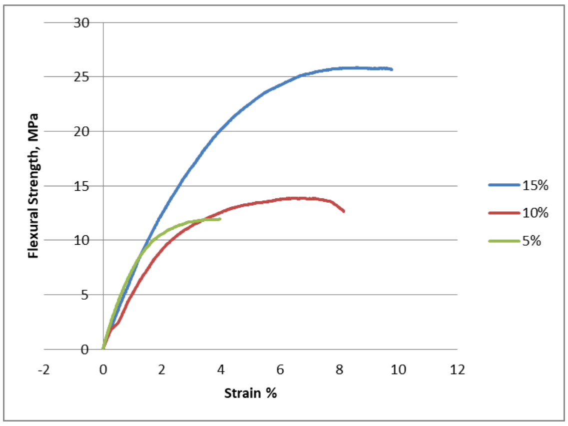



Figure 13. Stress strain curve

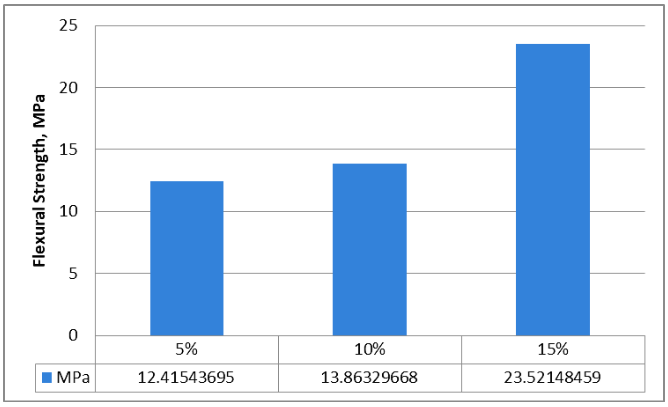



Figure 14. Flexural Strength of the composites

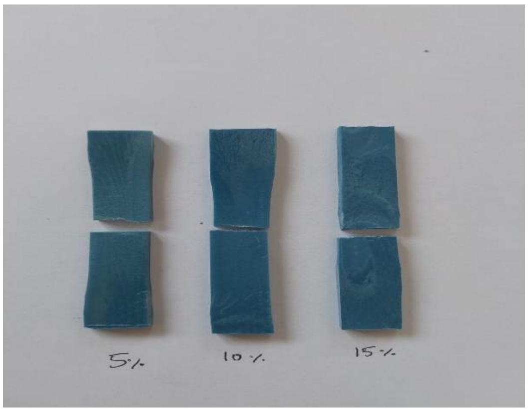



Figure 15. 5%, 10%, 15% CR Composite After Flexural Test

## 4.3 Impact Strength

Using an impact testing machine, the Izod method was used to quantify the amount of energy absorbed by composites with varied concentrations of Crump Rubber filler. Assessments of the energy absorption of each composite are provided in Table 5 and Figure 15. The overall average from five trial tests is used for assessment.

| Trials | 5% $J/mm^2$ | 10% $J/mm^2$ | 15% $J/mm^2$ |
|---|---|---|---|
| **1** | 15.2 | 24.2 | 30.3 |
| **2** | 16.7 | 20.2 | 29.6 |

| | | | |
|---|---|---|---|
| **3** | 15.5 | 19.4 | 31.5 |
| **4** | 12.9 | 18.6 | 28.7 |
| **5** | 17.6 | 21.3 | 27.5 |
| **Average** | 15.58 | 20.74 | 29.52 |

The results reveal that GMB-HDPE-CR composites have a substantial impact resistance. Enhanced bonding, adhesion, and matrix dispersion contribute to augmentation in impact resistance.

Due to the reduction of composite porosities, the addition of Crump Rubber to the matrix, led to an improvement in impact strength, enabling the composite to absorb more energy.

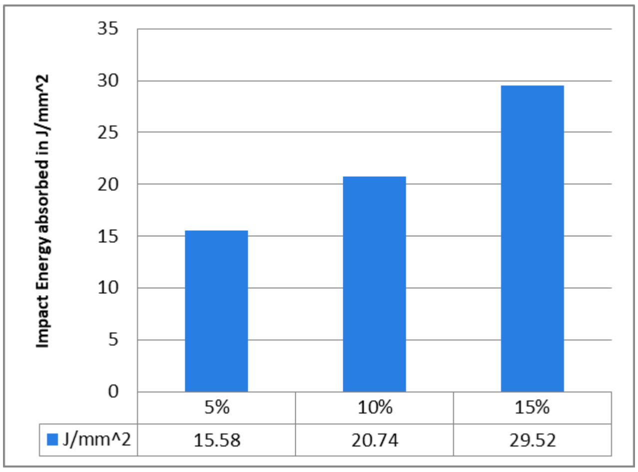



Figure 16. Impact Strength of the composites

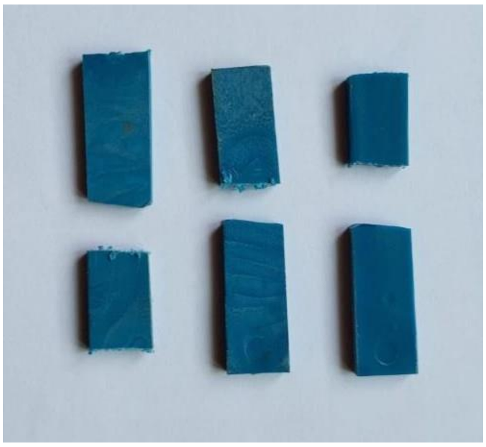


Figure 17. Specimens after Test

## 4.4 Hardness Strength

Composites of 5, 10, and 15% Crump Rubber filler were determined by conducting Rockwell Hardness Tests in accordance with ASTM D240 standards. Five Trials were conducted and average of the value is taken for evaluation.

The findings reveal that composites containing 15% CR have higher hardness strength than composites. The enhancement of bonding, adhesion, and Filler dispersion in the matrix contribute to the increase in hardness, which leads in enhanced strength.

| Trials | 5% (RHB) | 10% (RHB) | 15% (RHB) |
|---|---|---|---|
| **1** | 17.33 | 21 | 21.66 |
| **2** | 19.33 | 22.33 | 25.33 |
| **3** | 21 | 18.66 | 27.66 |
| **4** | 22.33 | 18.99 | 29 |
| **5** | 21.66 | 21.25 | 26 |
| **Average** | 20.33 | 20.446 | 25.93 |

5% Crump Rubber composites are reported to have a lower hardness due to formation of voids. It has been observed that composite laminates containing 15% Crump Rubber are harder. Thus, the addition of Crump Rubber would raise the composite's hardness. Crump Rubber consists of a solid wall surrounding strong core that acts as a barrier to boost the material's strength.

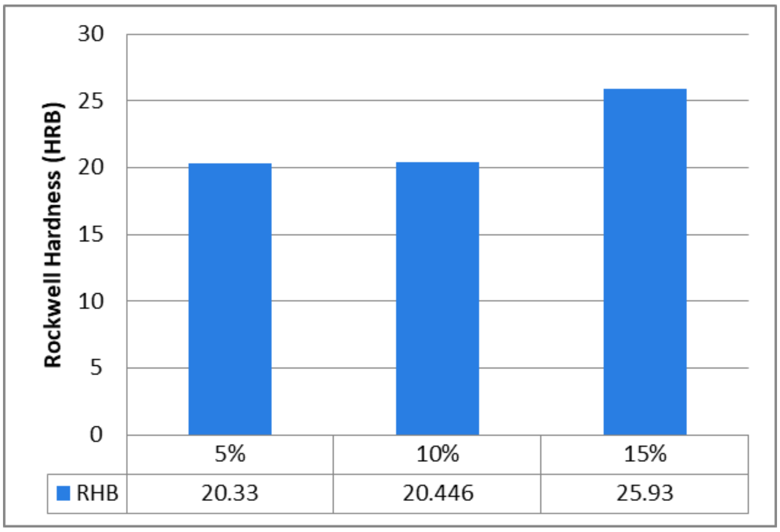



Figure 18. Hardness Strength of the composites

## Conclusion

- Addition of Crump Rubber to composite materials leads to improved hardness, impact resistance, flexural strength, and tensile strength.
- Composite of 15% CR is observed to be harder and exhibit improved impact resistance due to enhanced bonding and matrix dispersion.
- The addition of CR fillers to HDPE-GMB also improves flexural strength by nearly 100% compared to 5% CR filled composite.
- Linear increase in stress with load was observed up to the breaking point, and 15% Crump Rubber filled composite has a 50% higher UTS than 5% CR composite,
- All of the test results (Trials) are remarkably consistent and convergent, demonstrating an effective manufacturing method

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